YIELD POINT ELONGATION IN Al-Mg ALLOYS

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ABSTRACT The effects of temperature and strain rate of the tensile test, Mg content and grain size on yield point elongation were studied in Al-Mg alloys. It was found that yield point elongation was almost constant at test temperatures below 313K. Above 313K, it decreased rapidly, disappearing completely at 423K. Yield point elongation was observed to increase lineally with increasing strain rate. With increasing grain size of the specimen, yield point elongation showed significant decrease and above a critical grain size of 150μm, its formation was completely suppressed. Yield point elongation increased lineally with increasing Mg content.

Keywords: *Yield point elongation, Al-Mg alloys, grain size, Cottrell atmosphere*

1. INTRODUCTION

Yield point elongation is detrimental in press forming of thin metal sheets, since it induces so called stretcher strain marking on the surface of product materials. In the past, yield point elongation has been studied mostly in the case of low carbon steel sheets [1]. In a marked contrast, only a few investigations[2,3] have been made in the case of Al-Mg alloys. Therefore, influences of various metallurgical factors and deformation parameters in the tensile test have been known only qualitatively. It is therefore tried in the present investigation to clarify the effects the condition of the tensile test, i,e., the effect of the temperature and strain rate of the tensile test on the yield point elongation quantitatively in detail in commercial 5052(Al-2.2%Mg) alloy. Also the effects of the Mg content and grain size on yield point elongation were studied in high purity Al-Mg alloys prepared in the laboratory.

2. EXPERIMENTALS

2.1 Effect of temperature and strain rate of tensile test

Tensile test specimens with 60mm gage length and 25mm width were cut from commercial 5052 alloy sheets(1mm thick). They were solution treated at 723K for 1.8ks and cooled in the furnace. They were then subjected to the tensile test using an Instron type tensile test machine.

The effect of test temperature was investigated by varying test temperature between 238K and 453K at a constant strain rate of $3 \times 10^{-3}s^{-1}$. The effect of strain rate was studied by varying strain rate in the range between $3 \times 10^{-5}s^{-1}$ and $3 \times 10^{-2}s^{-1}$ at a constant temperature of 293K. The yield point elongation was determined on the stress-strain curves of these specimens.

2.2 Effect of grain size

Hot bands of high purity Al-5%Mg alloys containing Fe in the range between 0 to 0.4% were annealed at 723K for 1.8ks. They were subsequently cold rolled 80% to the thickness of 1mm and annealed at various temperatures between 573K and 773K for 1.8ks followed by air cooling. With this method, grain sizes in the range between 25μm and 160μm could be obtained. On these specimens, tensile tests were made at room temperature with a strain rate of $3 \times 10^{-3}s^{-1}$.

2.3 Effect of Mg content

Hot bands of high purity Al containing Mg up to 9% were solution treated at 723K for 1.8ks and cooled in air. They were further cold rolled 80% to the thickness of 1mm and finally annealed at 723K for 1.8ks followed by furnace cooling. Tensile tests were made on these specimens at room temperature with a strain rate of $3 \times 10^{-3}s^{-1}$.

3. RESULTS AND DISCUSSIONS

3.1 Effect of temperature of tensile test

Al-2.2%Mg alloy specimens cooled in furnace from 723K were tested at temperatures between 238K and 453K with a strain rate of $3 \times 10^{-3}s^{-1}$. Yield point elongation determined on

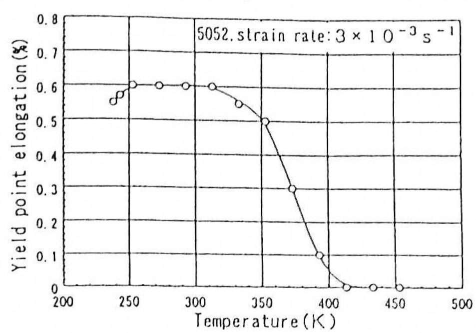

Fig. 1 Effect of test temperature on yield point elongation.

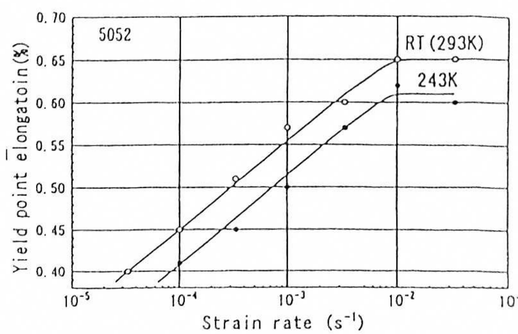

Fig. 2 Effect of strain rate on yield point elongation.

these specimens is plotted in Fig.1 against the temperature of the tensile test. At temperatures between 253K and 313K, yield point elongation was constant. Above 333K, it decreased rapidly with increasing test temperatures, and above 423K, it was not observed at all. Similar observations have been made in low carbon steels [4]. In that case, yield point elongation increased with decreasing test temperature down to 223K. Below 223K, yield point elongation was found to be constant. These changes in yield point elongation in low carbon steels were explained in terms of the temperature dependence of the velocity of Lüders band propagation [4]. However, the decrease in the yield point elongation observed in Al-2.2%Mg alloy at temperatures above 423K, Fig.1, would be more properly explained in terms of the decomposition and disappearance of Cottrell atmosphere of Mg atoms.

3.2 Effect of strain rate

Al-2.2%Mg alloy specimens cooled in the furnace from 723K were strained at 293K by varying the strain rate in the range between $3\times10^{-5}s^{-1}$ and $3\times10^{-2}s^{-1}$. Similar test were also performed at 243K. Yield point elongation determined in these tests are plotted in Fig.2 against the strain rate. At both test temperatures yield point elongation increased linearly with increasing strain rate. However, at strain rate above $1\times10^{-2}s^{-1}$, yield point elongation was constant, irrespective of the strain rate.

Also in low carbon steels, it has been observed that yield point elongation increases linearly with increasing strain rate [5,6]. This has been explained [6,7] in terms of a simple equation:

$$\varepsilon_L = \frac{L_0}{V_L} \cdot \dot{\varepsilon} \qquad (1)$$

where ε_L, L_0, V_L and $\dot{\varepsilon}$ represent yield point elongation, gage length of the tensile test specimen, Lüders band velocity and strain rate, respectively. Eq.(1) clearly shows that, if the Lüders velocity is constant, yield point elongation is proportional to the strain rate. Also results given in Fig.4 can be quite well explained with this equation. As is already pointed out above, yield point elongation was constant at strain rates above $1\times10^{-2}s^{-1}$. This may be related with the limited dynamic response of the pen recorder system used in the present investigation.

Figure 2 further shows that yield point elongation observed at 243K was always smaller with a constant amount than that determined at 293K, yielding two parallel straight lines. According to Eq.(1), this indicates that the Lüders band velocity is the same at these two test temperatures. Only strains induced in the already yielded regions might be different by a constant amount.

3.3 Effect of grain size

In Fig.3, yield point elongation observed in high purity Al-5%Mg-Fe alloys is plotted against their grain sizes. It is seen that yield point elongation decreased dramatically with increasing grain size, disappearing abruptly at grain sizes above 130μm. Thus, it is evident that critical grain size exist in inducing yield point elongation.

In low carbon steels,it has already been known that yield point elongation is large in fine grained materials [5,8]. In an Al-3%Mg alloy, Chadwick and Hooper [3] found that random marking due to yield point elongation did not appear above a critical grain size of 0.05 mm.

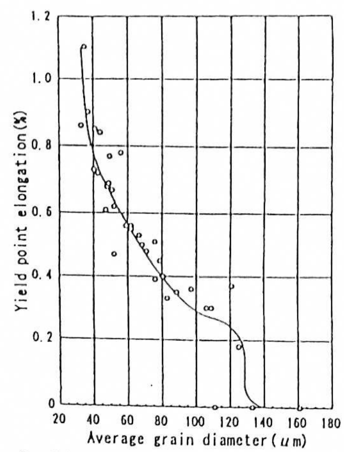

Fig. 3 Effect of average grain diameter on yield point elongation.

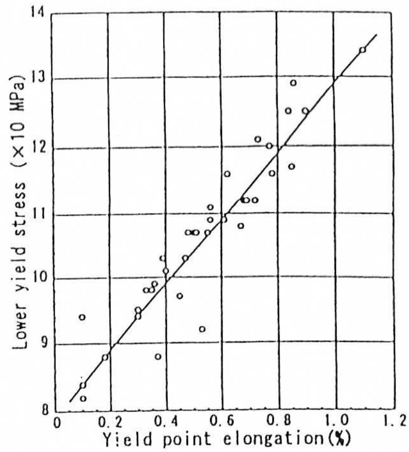

Fig. 4 Relation between yield point elongation and lower yield stress.

Philips, Swain and Eborall [2], on the other hand, found that, in Al-3.5%Mg alloys, yield point elongation could not be observed above a critical grain size of 0.04mm. All these results are in qualitative agreement with the results given in Fig.5.

In Fig.4, the relationship between yield point elongation and the lower yield stress of these specimens are illustrated. Yield point elongation increased lineally with increasing lower yield stress, giving the following equation

$$\sigma_L = A + B \cdot \varepsilon_L \qquad (2)$$

where A and B are constants, whereas σ_L and ε_L represent the lower yield stress and the yield point elongation, respectively. In low carbon steels, Butler [9] obtained the following relationship.

$$\sigma_L = A + B \cdot \log \varepsilon_L \qquad (3)$$

At small ε_L, which is usual in Al-low Mg alloys, Eq.3 is equivalent to Eq.2.

It is readily shown that the following equation can be derived from Eq.3 and Hall Petch relationship [7], $\sigma_L = \sigma_0 + k\,d^{-1/2}$ (σ_0 and k are constants)

$$\varepsilon_L = C + D \cdot d^{-1/2} \qquad (4)$$

where C and D represent constants. The observed results are replotted in the form given by this equation. The results are illustrated in Fig.5. It is evident the observed results can be quite satisfactorily described with Eq.3. If the mechanism of the deformation of polycrystals proposed by Hall and Petch is taken into account, $d^{-1/2}$ represents the stress concentration induced by the slip band developed in the neighbouring grain. Eq.3 therefore indicated that, if such stress concentration is large due to larger grain sizes, propagation of deformation in the form of discontinuous Lüders band becomes increasingly difficult. However, it would be more appropriate to consider that the term $d^{-1/2}$ in Eq.3 is somehow related to the strength of constraints imposed on a specific deforming grains from surrounding neighbouring grains. Since such constraints are weak in coarse grained materials, each grain can deform independently, yielding surface roughning, i,e., so called orange peels, instead of yield point elongation. Fujita [10] has found that such constraints are lost, if the number of grains contained in the specimen thickness is smaller than the critical value. In an Al specimen with the grain size of 100μm he has found that, this corresponds to 5 grains. These may be the reasons why yield point elongation is not observed above a critical grain size.

3.4 Effect of Mg content

High purity Al-Mg alloys containing Mg up to 9% were furnace cooled from 723K. They were strained at room temperature with the strain rate of $3 \times 10^{-5} s^{-1}$ and $3 \times 10^{-3} s^{-1}$. In Fig.6, yield point elongation was plotted against Mg content. It is shown that yield point elongation increased with increasing Mg content up to a certain critical Mg content. At higher Mg content above 7%, it was not observed at all.

Philips, Swain and Eborall [2] investigated yield point elongation in Al-3.5%Mg and Al-7%Mg alloys slowly cooled from 675K. It was found that yield point elongation in the Al-3.5Mg alloy was 1.63%. In the Al-7%Mg alloy, it was much smaller amounting only to 0.44%. Such small yield point elongation was ascribed to the precipitation of the β phase, which would be well expected in Al- high Mg alloys. The same explanation would be applicable to the results given in Fig.6. With increasing Mg content, Mg atoms in solution are increased, so that

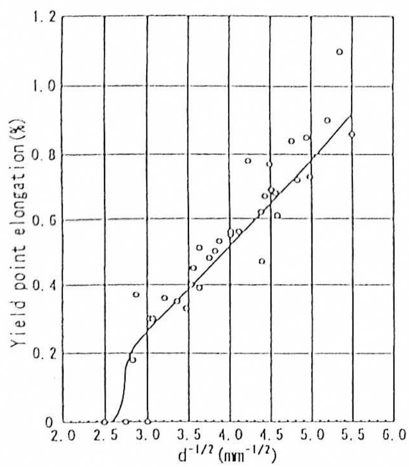

Fig.5 Yield point elongation plotted against $d^{-1/2}$

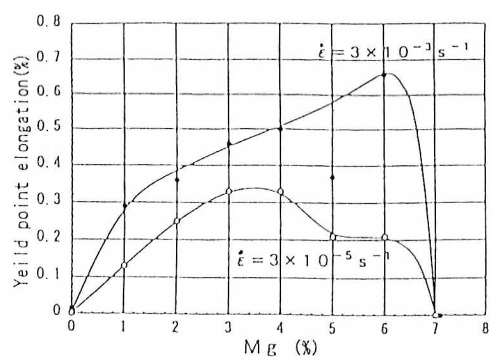

Fig.6 Effect of Mg content on yield point elongation.

pinning of dislocations becomes more perfect, yielding larger yield point elongation. At higher Mg content, Mg atoms are precipitated as coarse β phase particles, so that pinning of dislocations becomes less effective, reducing yield point elongation.

4.Conclusions

In Al-Mg alloys, effects of grain sizes and Mg contents, and temperatures and strain rates of the tensile test on the yield point elongation have been investigated. Conclusions obtained are as follows:

(1) In 5052 alloy, yield point elongation increases linearly with increasing strain rate of the tensile test.

(2) In 5052 alloy, yield point elongation is almost constant at test temperatures below 313K. Above 313K, it decreases rapidly with increasing test temperatures, disappearing completely at 423K.

(3) In high purity Al-5%Mg alloys, yield point elongation decreases rapidly with increasing grain size. Above a critical grain size of 150μm, it is completely absent.

(4) Yield point elongation increases with increasing Mg content. At higher Mg content, however, Mg atoms precipitate extensively as the β phase, so that the Mg atoms available to dislocation pinning are reduced, yielding smaller yield point elongation. At Mg content above 7%, yield point elongation is absent.

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